Intensity Modulated Radiation Therapy with volumetric modulation (VMAT)

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Abstract

IMRT (Intensity Modulated Radiation Therapy) is the latest radiotherapy technique for high dose treatment of complex shaped tumors or neoplasm close to sensitive organs at risk. VMAT (Volumetric Modulated Arc Therapy) is next generation arc therapy technique which performs uninterrupted arc(s) around the patient, dramatically speeding treatment delivery and reducing treatment times to those required for "conventional" radiation therapy. Beam modulation is obtained by continuous changes in collimator morphology on the basis of target shape and in dose rate during gantry rotation around the patient. Since November 2010, in our institution, 257 patients were treated with VMAT. Plan evaluation was performed using Homogeneity and Conformity Index and a phantom (Delta 4) to control correspondence between calculated and delivered dose. In our experience VMAT provides to dose distributions comparable with most of other IMRT systems, but with a dramatic shortening of delivery time with considerable advantages in terms of treatment reproducibility (reduction of intrafraction movement of the patient), radioprotection and organization of LINAC spaces.

Introduction

IMRT represents the most recent evolution of radiation technologies. It allows improvement of therapeutic index both arising tumor control probability, due to dose increment to target, and reducing side effects.

Dose modulation and escalation can be achieved by an increment of beam number, a gantry rotation (arc therapy), multileaf collimator (MLC) shape dynamic modification or dose rate modulation (fig 1).

The main limit of IMRT treatments is represented by long fraction delivery time and high number of monitor units per fraction. Furthermore, using a multiple field-IMRT or Serial Tomotherapy, radiation linkage and scattering is not trascurable, probably affecting effective delivered dose.

The aim of this paper is to describe a dynamic IMRT technology, VMAT® (Volumetric Modulated Arc Therapy), in use in Radiation Oncology Unit of "Vito Fazzi" Hospital (Lecce) since November 2010. In particular, we will describe VMAT application in the care of Head and Neck, Pelvic primitive neoplasm

and brain metastasis and its utility in

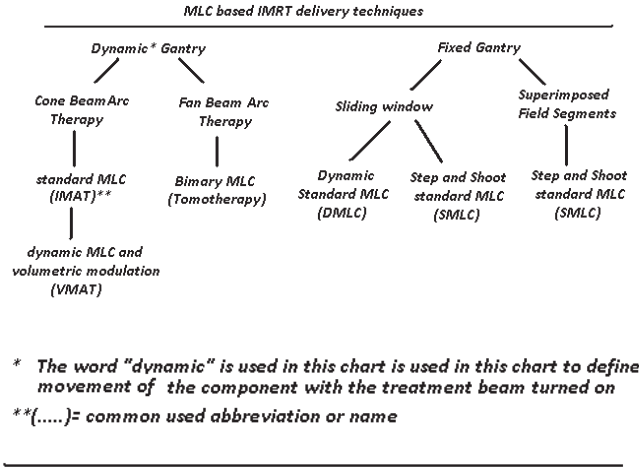

Fig.1: Multileaf collimator (MLC)-based intensity modulated radiation therapy (IMRT) delivery techniques.
DMLC: dynamic multileaf collimation
IMAT: intensity modulated arc therapy
SMLC: segmantal multileaf collimation

Materials and methods

VMAT delivers radiation by rotating the gantry of linac around the patient through one or more arcs with radiation continuously on. As it do so, a number of parameters can be varied. These include:

- MLC aperture shape
- the fluence output rate (dose rate)
- the gantry rotation speed
- the MLC orientation [1]

Treatment is performed by rotating the gantry over a single or dual arc(s), with MLC set and shaped to cover target. This entails rapid execution of a sequence of control points each defining multileaf collimator (MLC) shape, MLC segment dose, and a gantry-angle window across which each shape sweeps dynamically (Fig 2).

The genesis of the method was with intensity modulated arc therapy (IMAT) from Cedric Yu back in 1995, but VMAT adds the variability of parameters above mentioned, thus reducing the need to use as many arcs as there are maximum number of field components (fig 1).

VMAT can deliver highly conformal dose distributions similar to those created by other forms of intensity-modulated radiation therapy (IMRT), including the multiple-static overcoming IMRT limits.

field MLC technique, the dynamic MLC (DMLC) technique, static and helical tomotherapy, the CyberKnife, scannedbeam therapy and so on (hereafter referred to as "conventional" IMRT).

Provided that the gantry speed can be varied continuously, it does not require a continuous variation of fluence-output rate to obtain a continuous variability of fluence output rate per degree.

The minimum fluence-output rate and the maximum gantry speed determine the constraining minimum fluence output rate per degree. Where there is a maximum fluence-output rate and minimum gantry speed, there will be a constraining maximum fluence output rate per degree.

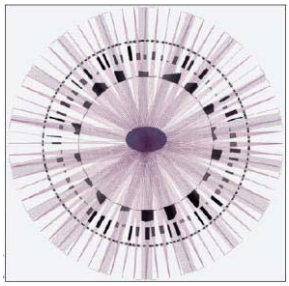

Fig 2: VMAT: the divergent ray paths, leaf positions and segment weighting at each gantry angle. The reconstructed parallel rays and associated intensity-modulated beam are shown for every 4th angle. From a set of unmodulated VMAT fields. the parallel rays are spatially modulated.

Since November 2010, in our institution, 257 patients were treated with VMAT. Schematic representation of patients who underwent to this therapy and their disease is shown in table 1.

In every patient, a 3 mm thickness-CT scan of tumor site was acquired in treatment position. On every slice were defined one or more PTV(s) (planned target volume) and the organs at risk of side effects development (OARs). Treatment planning was calculated on Oncentra Masterplan®, using a specific inverse planning system. Treatment plans were evaluated using isodose distribution, DVH (dose-volume histogram) and a quality index (CI) :

Conformity Index (CI): $\frac{TV_{RI}}{TV} \times \frac{TV_{RI}}{V_{RI}}$;

TV_{RI} : Target volume covered by the reference isodose; *TV:* Target volume; V_{RI} : Volume of the reference isodose)

Disease site	Number of patients
Head and Neck	91
Lung	31
Brain	30
Prostate gland	29
Gynecologic neoplasm	29
Anus	11
Superior Abdomen	11
Rectum	5
Oesophagus	5
Boost in craniospinal irradiation	5
Other	10
Total	257

Table 1: patients treated with VMAT in our istitution

In every treatment plan, target volumes called PTV were delined and a potential curative dose is prescribed. To avoid or to reduce incidence of side effects, constraints to OARs were individuated. These constraints corresponds to doses that produce toxicity in 5% of cases in 5 years (table 2) (2-10).

Target coverage and OARs doses are evaluated on DVH.

Organ at risk	*Constraints*
Spine	D_{max} = 45Gy
Brainstem	D_{max} = 54Gy
Parotid Glands	D_{mean}= 26Gy
Eye	D_{mean}= 35Gy
Lens	D_{max} = 5Gy
Optic nerve	D_{max} = 60Gy
Optic chiasma	D_{max} = 54Gy V_{60} = 1%
Small bowel	V_{15}< 120cc V_{45}<195cc
Rectum	V_{50}< 50% V_{60}< 35% V_{65}< 25% V_{70}< 20% V_{75}< 15%
Bladder	V_{65}< 50% V_{70}< 35% V_{75}< 25%
Femoral heads	V_{40}< 40% D_{max}= 50Gy

Table 2: OARs in Head and Neck and Pelvic neoplasm treatment and constraints commonly used in IMRT plans

Head and Neck

In Head and Neck cancer treatment, three PTVs with three different dose levels were defined as below:

- PTV1: primary and positive nodes. Prescription dose 69.9 Gy in 2.33 Gy-daily fractions
- PTV2: nodes at high risk of subclinical involvement. Prescription dose 60 Gy in 2 Gy-daily fractions
- PTV3: nodes at low risk of subclinical involvement. Prescription dose 54 Gy in 1.8 Gy-daily fractions

Total fractions number is 30.

Organs at risk to develop toxicity were:

- spine
- brainstem
- parotid glands
- optic and ocular structures (eyes, lenses, optic nerves, optic chiasma)

Contouring of PTVs and OARs is shown in fig. 3.

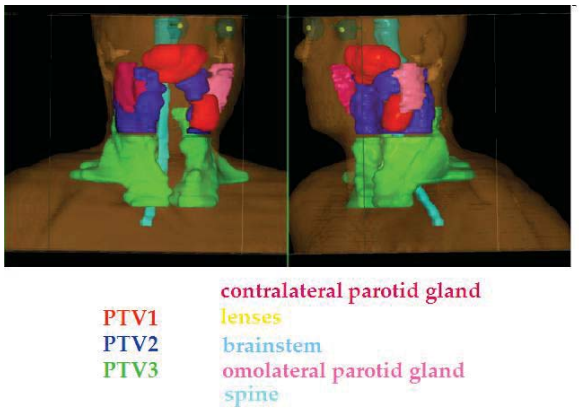

Fig 3: Example of contouring in Head and Neck cancer: 3D-reconstruction of Target Volumes and Organs at Risk

Pelvic Malignancies

Prostate cancer

In Prostate Cancer, treatment volumes were often represented by prostate and seminal vescicles (fig 4A).

Prescription dose were 78.4 Gy in 35 fractions for prostate (fraction dose: 2.24 Gy)and 66.5 Gy for seminal vescicles (fraction dose: 1.9 Gy).

In case of high risk of subvclinical involvement, prophylactic irradiation of pelvic nodes was indicated. In this case, target volumes and prescription doses were PTV1 (prostate, seminal vescicles and macroscopically involved nodes) treated with 70 Gy and PTV2 (negative pelvic nodes) treated with 50-56 Gy in 28 fractions

(fraction doses 2.5 and 1.8-2 Gy respectively) (fig 4B).

Ginecologic cancers

PTVs (fig. 5) and prescription doses were:

- Tumor side and involved Nodes: 66 Gy 30-33 fraction of 2.33-2 Gy
- Rest of uterus (when it is surely not involved; PTV2): 60 Gy in 30-33 fractions of 2-1.8 Gy
- Negative nodes (PTV3): 54-56 Gy in 30-33 fractions of 1.8-1.7 Gy

OARs were small bowel, rectum, bladder.

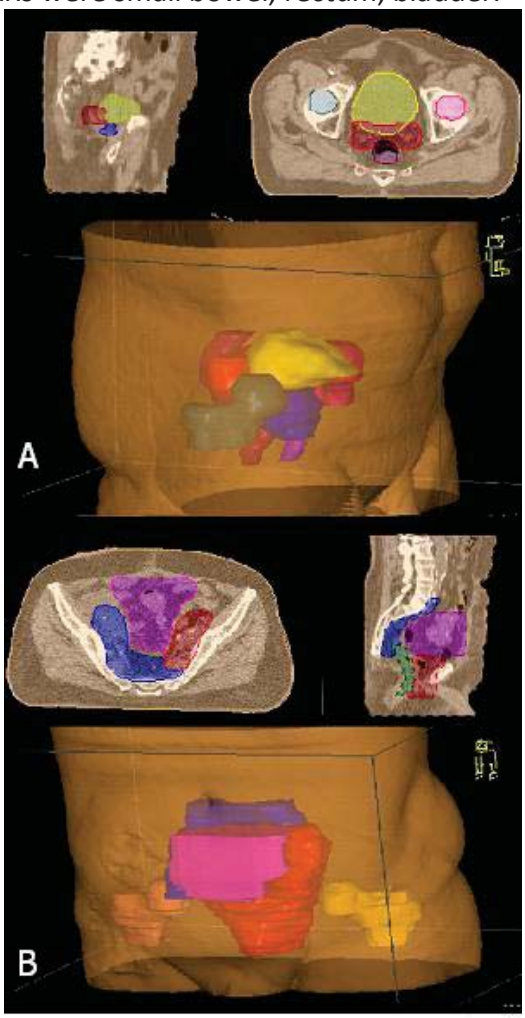

Fig. 4: example of contouring in prostate cancer and 3D reconstrauction of PTVs and OARs
A: without lymphnodes
B: with lymphnodes

Brain metastasis

IMRT with VMAT was indicated in patients with 1-3 brain metastases (maximum diameter of largest metastasis ≤ 3 cm). A GTV (Gross Tumor Volume) including the lesions macroscopically visible was delined on CT scan. PTV1 derived from GTV with 3mm margin. PTV2 included the whole brain.

Prescription doses were: 40Gy in 4Gy-daily fraction for PTV1 ≥ 2cm and 50Gy in 5Gy-daily fractions for PTV1 <2cm.

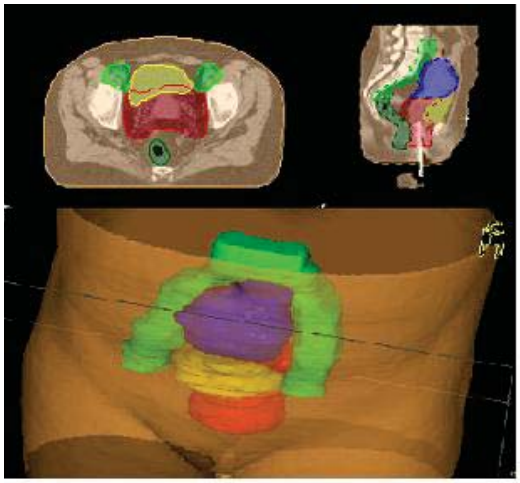

Fig. 5: Example of contouring in Gynecologic Cancer and 3D reconstruction ovf PTVs and OARS

Total dose for whole brain was 30Gy in 3Gy-daily fractions.

OARs were:

- Ocular and optic structures
- Auricular and acoustic structures
- Brainstem

Results

In every treatment plan, high dose conformation around target was required before final approval. In particular, all plans had Conformity Index included between 0 and 1, that means in line with IMRT protocols or with only a minor violation.

In ***Head and Neck cancer***, spine sparing was performed in all plans and parotid sparing was achievable in 90% of cases.

In all plan 95% of prescribed dose covered 95% of target volume (fig. 6A). To obtain acceptable dosimetric result and OARs sparing, it was necessary to program treatment usin two 340-degree arcs.

Fraction duration was 12-20 minutes.

In ***Pelvic Malignancies*** bladder and rectum sparing was achievable in all treatment plans

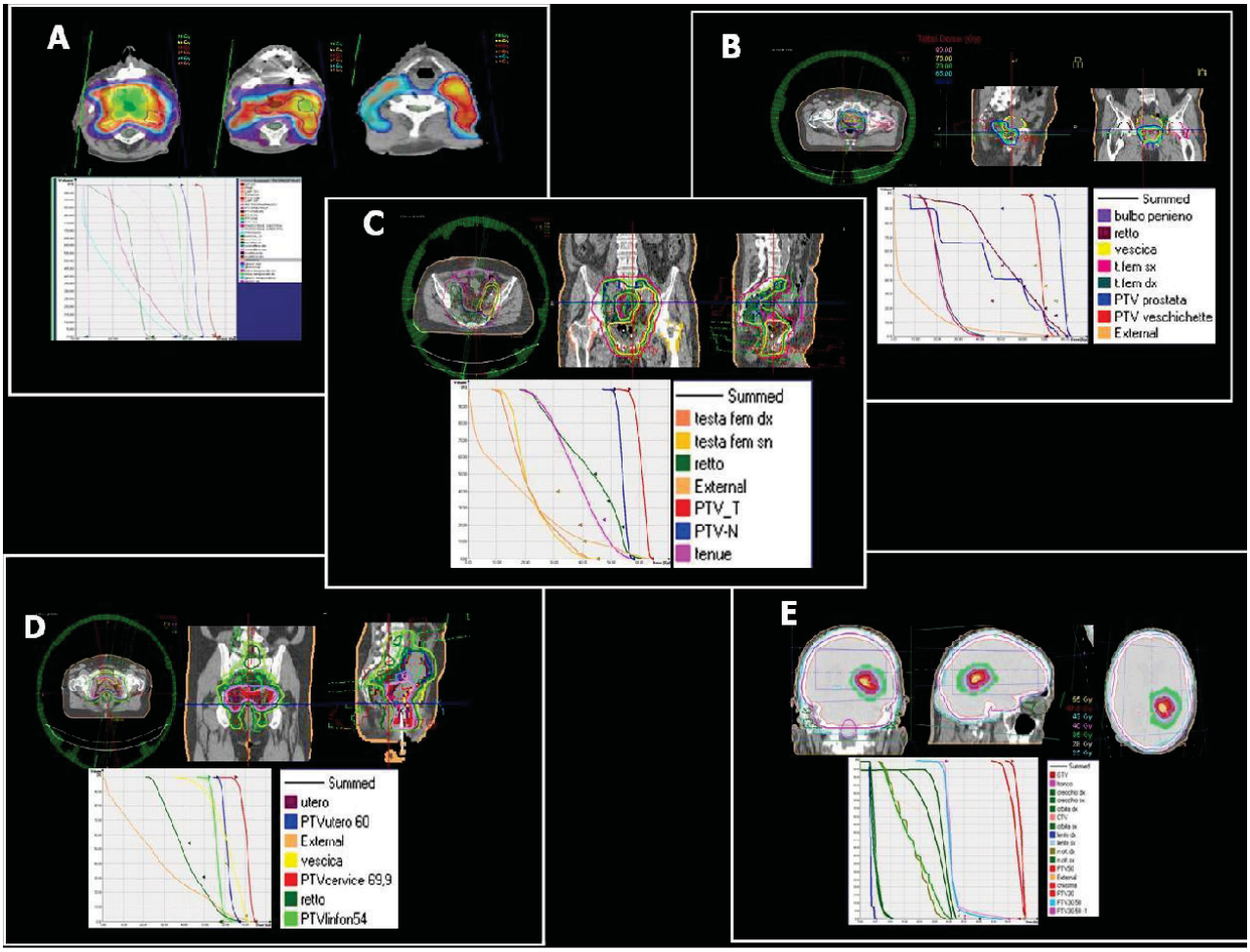

Fig. 6: Dosimetric results and Dose Volume Histograms in Head and Neck cancer (A), Prostate Cancer (B: without nodes; C: with nodes), Gynecologic Cancers (D) and Brain Metastasis (E)

(fig. 6 B, C, D). In prostate cancer, when nodal irradiation was not required, acceptable dosimetric result could be achieved using only an arc. In this case, treatment duration was 5-7 minutes. To obtain an adequate coverage of
nodal pelvic chains, in prostate and gynecologic neoplasm, two 340° arcs are required, with a fraction time of 12-15 minutes.

Also in ***Brain Metastasis*** treatment, high dose and conformation around target and OARs sparing can be easily achieved using a double arc VMAT plan. Treatment duration was 12-15 minutes.

Discussion and Conclusions

VMAT is characterized by a series of technical advantages listed below:

- Fast Seamless Field Delivery
- Continuously Variable Dose-Rate
- Variable Gantry Speed
- Optimized Patient Positioning (couch movement in the three dimensions)
- Optimized Collimator Angle
- Seamless Field Delivery Interdigitation

These advantages provide to an easy delivery of intensity modulated radiation treatment and, in particular, simoultaneous delivery of different dose levels to different target volumes (SIB: simultaneous integrated boost).

SiB obtained with a single treatment plan, allows reduction in overall treatment time with consequent reduction in tumor repopulation probability. Moreover, using a daily fraction higher than 2 Gy (daily-2 Gy = Conventional Fractionation= CF), biological

equivalent dose (BED) on target volume is higher than the nominal dose , with an improvement in tumor control probability. The calculation of BED is effectuated using the formula below:

$$BED = D \quad \frac{\alpha/\beta + d}{\alpha/\beta + 2}$$

Where: D= nominal prescribed dose; α/β= ratio specific for different tissue, describing tissue sensibility to radiation; d= fraction dose; 2= dose fraction in CF.

Result of VMAT optimization may, however, depend on number of arcs, maximal delivery time and gantry angle spacing between subsequent control points. Some studies demonstrate that a single arc can achieve dosimetry comparable with IMRT for prostate cancer, but not for more complicated PTV, so in most cases a double arc treatment is necessary to achieve acceptable dosimetric results, affecting the duration of fraction delivery.

Although in a study single arc-VMAT seems to produce in Head and Neck cancer similar dosimetric results with less Monitor Unit than Step and Shoot IMRT (11), most series suggest that dual arc provide to an higher plan quality. Using dual arc increase calculation time. However, both single and dual arc reduce delivery time compared with other IMRT. Optimization usin larger spacing between control points can reduce calculation time. In fact, dosimetric result are comparable using an interval of 6° or 4° or 2° (12)

In treatment of brain metastasis with SIB and high dose fraction, with a theoretical arising of tumor control probability, there is an increased probability of developing side effects like cognitive functions. A study demonstrate that this effect is more evident in questionnaire of patients treated with SIB-higher fraction doses, without a worsening in Quality of Life (13).

VMAT is a quite rapid IMRT technique. It is more accurate and efficient in delivery than the other IMRT, because of a drastic (8.5%) reduction in Monitor Unit (11). This data suggest that VMAT could be the ideal technique to treat also volume fast modifying (e.g. bladder).

In our experience, VMAT is an efficient IMRT technology, able to join excellent dosimetric results with rapid delivery. Unfortunately, the calculation time is too long and this creates difficulties in Radiotherapy and Physics Units organization since it is necessary that part of the staff has to be exclusively dedicated to the optimization of these treatment plans.

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